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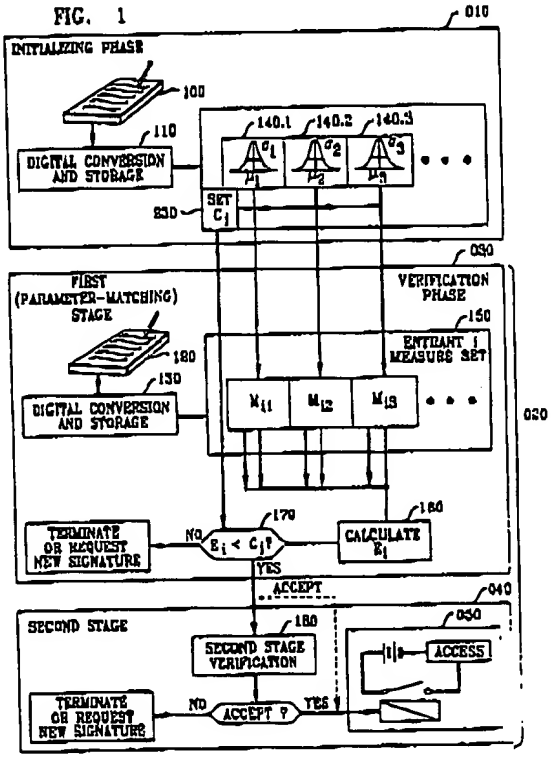
## (54) Method and apparatus for controlling a system, using signature verification.

(57) Forged signatures are discriminated from authentic signatures in a verification process which relies on dynamic signature properties. In an initialization phase (010) a reference set of authentic signatures is obtained. A set of dynamical properties (140.1, 140.2, 140.3) of the reference signatures is computed numerically. The most characteristic subset of such properties is selected and statistically analyzed to obtain a set of parameters for signature verification. An entrant signature is subsequently accepted or rejected (160, 170) based on its conformity to the parameters. An accepted signature is optionally passed along to a higher-level verification process. When a signature is accepted by the highest-level verification process, responsive means (050) are activated, resulting in the entrant's access to a system.

FIG. 1

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## Field of the Invention

This invention relates to the field of pattern recognition, and more specifically, to the verification of handwritten, human signatures.

## Art Background

The automatic verification of a signature is a useful way to identify a human being for purposes, e.g., of establishing his authority to complete an automated transaction, or gain control of a computer, or gain physical entry to a protected area. Signatures are particularly useful for identification because each person's signature is highly unique, especially if the dynamic properties of the signature are considered in addition to the shape of the signature. Even if a skilled forger can accurately reproduce the shape of a signature, it is unlikely that he can reproduce the dynamic properties as well.

Numerous practitioners have addressed the problem of signature verification. Some practitioners have concentrated on analysis of the static shapes embodied in signatures, whereas other practitioners have concentrated on analysis of dynamic properties. For example, a verification method that involves analyzing the dynamic properties of signatures is described in U.S. Patent No. 4,901,358, issued to L. Bechet on February 13, 1990. That patent discloses a verification method based on the x and y speed signals of the signature. Each speed signal is broken into standardized, short segments, and each segment is compared with a corresponding segment of a previously obtained reference signature. In a contrasting approach, U.S. Patent No. 4,024,500, issued to N.M. Herbst, et al. on May 17, 1977, discloses the use of the speed signal to separate the signature into segments, followed by shape analysis of the segments. A third approach is described in our European patent application No. 92304115.6. In that approach, a model signature is used as a reference for shape analysis. The model signature is constructed by affine invariant averaging of reference signature segments. In a speed-based segmentation method, each signature to be segmented is compared to a selected reference signature through the use of dynamic time warping.

However, when a person's (hereafter, an "entrant's") signature is verified according to one of the above-described methods, it is compared, segment-by-segment, to a reference signature. As a consequence, such methods require a relatively large amount of information about the reference signature to be stored. This requirement is disadvantageous in applications where the relevant reference information is to be stored at a remote location where only limited storage means are available. For such applications, it is desirable to characterize the entrant's signature by a set of numerical parameters which, although relatively small, still identifies that person's signature with a high degree of confidence.

Moreover, such a parameter-based technique, even if it fails to provide an acceptable confidence level, is useful in combination with more complex techniques (based, e.g., on pattern-matching) which offer greater confidence at the cost of greater delay or greater information storage requirements. In such a combination, the parameter-based technique is useful as a coarse sieve for rejecting gross forgeries or anomalous signatures, without the need to invoke the more complex technique.

A signature verification technique based on numerical parameters has, in fact, been described. U.S. Patent No. 3,699,517, issued to James W. Dyche on October 17, 1972, describes a technique in which sixteen components of a real-time signature vector are compared to the corresponding mean values computed on a reference set of previously obtained sample signatures. If a sufficient number of the components fall within a predetermined range of the respective mean values, the signature is accepted.

Although such a technique may offer advantageously low storage requirements and rapid processing, it is still relatively inefficient. In that regard, we have found that a given entrant's signatures can be dependably verified on the basis of fewer than sixteen parameters, particularly when the specific selection of parameters is adaptable to the idiosyncrasies of a given entrants's handwriting. Hitherto, practitioners have failed to provide such flexibility, and have consequently failed to provide a parameter-based signature verification method having extremely high efficiency.

## Summary of the Invention

In one aspect, the invention involves a method for controlling access to a system of the kind in which access is based on signature verification. The invention is typically practiced in a communications network, for example, a plurality of bank branches, each communicating with a central office via telephone lines, or a plurality of workstations intercommunicating via a local area network.

In preferred embodiments, an entrant submits sample signatures via digitizing means which facilitate the storage of the sample signatures in digital form. In an initializing phase, each entrant digitally records a set of at least two authorized sample signatures, here referred to as the "reference set," using the digitizing means. In a later, verification phase, a person (claiming to be an authorized

entrant having earlier recorded sample signatures) again digitally records a signature, here referred to as an "entrant signature." The verification process involves the calculation of one or more error values, hereafter referred to as "entrant errors", which represent the degree to which the entrant signature differs from the authorized sample signatures. If the entrant error is less than (or, alternatively, less than or equal to) a certain threshold, responsive means are activated, e.g., an electric circuit or logical operation is activated, such that the entrant is given access to the system. If the requirement is not satisfied, the entrant may, optionally, be invited to submit one or more additional entrant signatures for verification.

In the initializing phase of the preferred embodiment, the sample signatures are digitally processed, resulting in a set of at least four calculated values which are characteristic of the sample signatures and represent a certain group of spatial and dynamic properties, here referred to as "measures," of the sample signatures. A number, representing the average or most typical such value over the set of reference signatures, is calculated. Such a number is hereafter referred to as an "average". The currently preferred such average is the statistical mean. A number is also calculated, which represents the variability of the measure over the set of reference signatures. Such a number is hereafter referred to as a "deviation". The currently preferred such deviation is the statistical standard deviation. Significantly, and in contrast to the prior art, a subset consisting of the at least three measures having the smallest deviations over the set of reference signatures is selected for subsequent use in the verification phase.

As part of the initializing phase of the preferred embodiment, the threshold is calculated on the basis of information derived from the reference signatures. For each reference signature, each of the selected measures, evaluated for that signature, is compared to the corresponding average over the reference set. Such comparison leads to a set of calculated errors, one for each reference signature, with respect to the reference set. The threshold is determined on the basis of those errors, which are hereafter referred to as "reference errors".

The verification phase includes one or more stages, typically including a parameter-matching stage. In that stage, at least one entrant signature is digitally processed to evaluate the selected measures with respect to that signature. The entrant error is calculated by comparing these measure values to the corresponding mean reference values.

## Brief Description of the Drawings

FIG. 1 is a flowchart describing, in schematic fashion, the steps according to one embodiment of the inventive method.

FIG. 2 is a flowchart describing, in schematic fashion, an exemplary sequence of steps leading to the determination of a threshold useful in connection with the inventive method for rejecting forged signatures.

FIGS. 3 - 6 are bar graphs illustrating the ability of the invention to discriminate authentic signatures from forgeries.

## Detailed Description of a Preferred Embodiment

A system is provided, which is capable of offering access to, or withholding access from, a human being, here referred to as an "entrant". As noted, above, access is contingent upon successful verification of the entrant's signature.

If, for example, the system is an automated bank teller machine, such access is the ability of the entrant to conduct a banking transaction using the system. Access is exemplarily provided by activating an electric circuit which controls the system such that it can conduct a transaction. (Such activation of an electic circuit may, e.g., comprise setting a digitally stored value, or "flag," in a digital memory.) Other forms of "access" that may be provided by activating an electric circuit will be readily apparent, and include, e.g., deactivation of a physical locking mechanism, or setting a digitally stored value such that a computer or computer terminal will subsequently respond to the entrant's commands.

Exemplary digitizing means comprise a capacitance-sensing, transductive tablet which senses the position (i.e., the horizontal, or x coordinate and the vertical, or y coordinate) of the tip of a stylus, and transmits that information to a digital storage device (e.g., a digital computer). Preferably, such means are also capable of sensing, and transmitting data representing, the stylus pressure (exemplarily by means of a pressure transducer in the stylus). One suitable stylus-tablet inputting apparatus is described in co-pending U.S. patent application Serial No. 635,086, filed on February 28, 1990.

When a user is establishing his authorization as an entrant, he enters a reference set of at least two sample signatures. (The total number of signatures in the reference set is denoted by the positive integer n.) In fact, it is desirable for him to enter at least 5 signatures, and even as many as 10 or more. Each signature is recorded as a sequence of x-y coordinate pairs recorded at a uniform frequency of, e.g., about 300 points per second. Along with the spatial coordinates, a third coordi-

nate, pressure p, is optionally recorded at the same time points.

Although the recorded data are typically smooth, there are occasional gross outliers and noisy points which need to be removed (typically, less than 1% of the total). These are easily identified by their large Euclidean distance from the neighboring points.

According to a currently preferred embodiment, a smooth path is then constructed through the remaining x and y coordinates for each word in each signature. This is preferably done by smoothing each coordinate separately against time using a cubic smoothing spline.

In a currently preferred embodiment, the amount of smoothing is chosen automatically by global cross-validation of the integrated Euclidean distance between the observed and fitted points. Typically very little smoothing is performed, and the fitted curves usually come close to interpolating the observed sequences. There are three reasons for smoothing the signature sequences in this way: (1) even though the amount of smoothing is small, it tends to eliminate small discontinuities introduced by measurement error due to the discretization during the recording process, or small movements during the signing; (2) the cubic spline representation turns the sequence into a function that can be evaluated at any point t (this is convenient for purposes of subsequent steps); and (3) the cubic spline has two continuous derivatives, the first of which is used in the speed computation.

If the observed signature sequence is denoted by

$$X_i,\ i = 1, \ldots, N$$

measured at time points $t_i$, then the smoothed signature S(t) minimizes the criterion

$$\sum_{i=1}^{N} \|X_i - S(t_i)\|^2 + \lambda \int \|S''(t)\|^2 dt$$

over a suitable Sobolev space of functions, and for some value of the smoothing parameter $\lambda$. The solution varies dramatically with the value of the smoothing parameter, which has to be supplied. It is desirable to use the cross-validated integrated Euclidean squared distance

$$CV(\lambda) = \sum_{i=1}^{N} [X_i - S_{(i)}^{\lambda}(t_i)]^2$$

as a criterion for selecting $\lambda$. Here

$$S_{(i)}^{\lambda}(t_i)$$

is the value of the smooth curve evaluated at $t_i$; the subscript (i) indicates that the i-th point itself was omitted in the fitting of the curve. This criterion is desirable because it recognizes the signal in the signature, and selects a value for $\lambda$ such that only enough smoothing is performed to eliminate the small amount of measurement error.

A time-dependent speed signal is calculated for each of the n smoothed sample signatures. It should be noted in this regard that appropriate speed signals are generated by the exemplary smoothing method.

Each of the smoothed signatures may be characterized by a group of at least four *measures* which are readily calculable from the smoothed signature. Each measure is a well-defined mathematical property of a sampled signature which is potentially useful for identifying the writer of that signature because it varies relatively little between signatures made by the same writer. Such a measure represents spatial and/or dynamic properties of the signature. It should be noted, however, that although a group of relatively invariant measures can generally be found for any given writer, the same group generally will not work for other writers. Instead, different writers generally have different (relatively) invariant measures. From the individual measures, averages and deviations, as discussed above, are readily calculated as parameters which characterize the reference set as a whole.

One measure is simply the total path length L of the signature (optionally scaled by the horizontal width of the signature), which is readily calculable from the stored array corresponding to the sampled (and smoothed) signature. Another measure is the total duration T of the signature, which is calculable as the number of points sampled during the recording of the signature, divided by the sampling rate. Various other measures are readily calculated from the horizontal speed signal $v_x$, the vertical speed signal $v_y$, the horizontal acceleration signal $a_x$, and the vertical acceleration signal $a_y$. These quantities are defined, respectively, as the first derivatives, with respect to time, of horizontal and vertical position, and the second derivatives, with respect to time, of horizontal and vertical position. As noted, $v_x$ and $v_y$ are calculated by the currently preferred smoothing algorithm. The acceleration signals $a_x$ and $a_y$ are also readily calculated by well known numerical techniques.

The path velocity magnitude (speed) v is expressed in terms of the horizontal and vertical speeds by:

$$v = (v_x^2 + v_y^2)^{1/2}$$

The tangential acceleration $a_t$ is expressed in terms of the horizontal and vertical speeds and accelerations by:

$$a_t = (v_x a_x + v_y a_y)/v .$$

The centripetal acceleration $a_c$ can be expressed as:

$$a_c = (v_x a_y - v_y a_x)/v .$$

The magnitude a of the total acceleration is given by:

$$a = (a_x^2 + a_y^2)^{1/2} .$$

The time derivative j of acceleration, often referred to as "jerk," is also useful in this regard. Letting $j_x$ and $j_y$ represent, respectively, the time derivatives of $a_x$ and $a_y$, j may be expressed by

$$j = (a_x j_x + a_y j_y)/a .$$

Each of the quantities v, $a_c$, $a_t$, a, and j is readily calculated as a function of time. Using well known numerical techniques, the rms value of each of these functions over the sampled (and smoothed) curve is readily calculated. Such calculations provide, respectively, the following measures: the rms speed V, the rms centripetal acceleration $A_c$, the rms tangential acceleration $A_t$, the rms total acceleration A, and the rms jerk J. Additionally, the mean value of $v_x$ is readily calculated, providing, as a measure, the average horizontal speed $\bar{v}_x$. Additionally, well known numerical techniques are readily used to integrate $a_c$ over the curve, providing, as a measure, the integral, with respect to time, of the magnitude of the centripetal acceleration, $IA_c$. The above-described measures have been found to be useful, in practice. However, this list is not exhaustive. Instead, many other potentially useful measures will be apparent to the skilled practitioner.

In the initializing phase, a group of measures, exemplarily the nine measures described above, is calculated. It should be noted in this regard that the two main aspects of signature data, namely, shape and dynamics, have somewhat complementary roles in distinguishing valid signatures from forgeries. That is, the harder a forger tries to copy every detail of a signature's *shape*, the less likely he is to match its *dynamics*, and vice versa. Therefore the parameter-matching stage should include measures which tend to differentiate between shape and dynamics, so that if one aspect is matched, the other is mismatched. We have found that for the purpose of differentiating between shape and dynamics, a particularly useful group of measures are those relating to (i.e., representing, or derived from) path-tangential and path-normal properties of the motion of the stylus tip. Such measures include V, $A_c$, $A_t$, A, J, and $IA_c$, described above. Accordingly, the initializing phase preferably includes calculating at least one such measure.

As noted, an important limitation on the measures used is that their variability should be small over the reference set of signatures, in order to reduce the likelihood of false rejection of valid signatures. Since each signature has its own characteristics, which slowly vary over time, measures are preferably chosen according to each individual's reference set of signatures, and that choice preferably evolves as the reference set changes over time.

According to a currently preferred embodiment, the nine measures described above are evaluated for each signature in the entrant's reference set. A subset of the nine measures, comprising those measures having the smallest standard deviations (when each is normalized to the corresponding mean) is selected as the measure space for that entrant. Preferably, at least three measures are selected.

With regard to the verification phase, suppose an entrant signature is submitted by entrant i. Let $M_{ij}$ be the value of the j-th measure in the subset of $N_i$ measures selected for entrant i. (It should be noted that in general, not all of the measures that were evaluated for the reference signatures will be selected for use in the verification phase. Instead, a subset will be selected, including, e.g., only those measures displaying the smallest standard deviation over the reference set.) Also, let $\mu_{ij}$ and $\sigma_{ij}$ denote the mean and standard deviation, respectively, of $M_{ij}$ over the current reference set. The magnitude, $E_i$, of the error vector in this measure space for subject i is usefully defined as

$$E_i = \left[ \sum_{j=1}^{N_i} ((M_{ij} - \mu_{ij}) / \sigma_{ij})^2 \right]^{1/2} .$$

According to a currently preferred screening test, a cutoff threshold $C_i$ is determined from the reference set of entrant i. If $E_i$ is less than $C_i$ (or alternatively, *less than* or *equal to* $C_i$), the entrant signature is accepted. Otherwise, the signature is

rejected.

In typical applications, the objective of this screening procedure will be to quickly reject crude forgeries or errors in signing, but accept, for second-stage testing, signatures which may be either valid signatures or skillful forgeries. Accordingly, the error threshold should lie far enough above the largest error in the reference set to insure a very low false rejection rate.

According to the currently preferred embodiment, during the intializing phase, the error $E_i$ is calculated for each of the reference signatures, treating that signature as though it were an entrant signature. The greatest of the errors calculated in that way (i.e., the reference errors) is the yardstick for establishing the cutoff threshold $C_i$. That is, $C_i$ is set to be equal to the greatest reference error, or it is set to some incrementally higher value, such as 10% above the greatest reference error.

It should be noted in this regard that during the initializing phase, well-known statistical methods can be used for recognizing reference signatures having anomalous errors. Such anomalies might arise, for example, from non-reproduceable errors in the entrant's penmanship. Such anomalous signatures are optionally eliminated from the reference set.

The foregoing discussion is summarized in FIG. 1. Means 100 are provided for inputting a reference set of signatures, during the initializing phase 010, to digital conversion and storage means 110, which exemplarily comprise a digital central processing unit. Analogous (and, for at least some applications, identical) inputting means 120 and conversion and storage means 130 are provided for the entry and storage of at least one entrant signature in the verification phase 020. Data representing the reference set of signatures are processed to obtain a set of dynamical parameters, typically the mean and standard deviation over the reference set of each of a set of measures. For illustrative purposes, three such measures, 140.1, 140.2, 140.3, are represented in the figure. The verification phase includes a parameter-matching stage 030 and one or more optional second (and higher) stages 040. In the parameter-matching stage, the stored, digitized entrant signature is subjected to digital processing 150, resulting, in the example of the figure, in computed values $M_{i1}$, $M_{i2}$, and $M_{i3}$, corresponding, respectively, to measures 140.1 - 140.3. Significantly, only *selected* measures are evaluated in this stage. As noted, the index i identifies the entrant whose signature is being verified, and the index j here identifies one of the selected measures. In processing step 160, an error is calculated from the parameter values and the $M_{ij}$ values. In processing step 170, the error is compared to a threshold value. If the error exceeds the threshold, the signature is rejected. At this point, a new submission of an entrant signature may be requested, or the transaction with the entrant may simply be terminated. If the signature is accepted, and if there is only one verification stage, electric circuit 050 is activated, making access to a system available to the entrant. (For purely illustrative purposes, such activation is depicted in the figure as activation of a relay.) If, as depicted in the figure, the verification phase has a second stage, the stored signature data are subjected to a second stage verification process 180 resulting, as before, in either rejection, or acceptance and granting of access, or acceptance and invocation of a still higher verification stage.

Significantly, in the parameter-matching stage 030, the entrant signature is compared against a relatively small amount of data relating to the reference set. Such data consist of the identities of the selected measures, the means (or other averages) and standard deviations (or other deviations) of those measures over the reference set, and the threshold value. As part of the initializing phase, those data are conveniently digitally stored at a site which is local relative to the entrant. Such a site is, e.g., associated with a computer terminal or automatic teller machine through which the entrant conducts transactions with the access-controlled system. A particularly convenient location for such storage is a small, portable object such as a credit card equipped with a digital data storage medium (e.g., magnetic storage or a solid state microchip memory device) and carried by the entrant.

Accordingly, an embodiment of the invention is readily envisioned in which the initializing phase includes local storage of data, as described. In a subsequent, parameter-matching stage, the data are entered into the access-controlled system from the local data storage medium.

## Example

The initial database obtained for this study included reference sets, of 10 signatures each, belonging to the four human subjects identified as EP, FS, SG, and WN. Forgeries were also obtained as follows: of the signature of subject EP, 10 forgeries; of FS, 9; of SG, 4; and of WN, 10. The four forgers were volunteers who were shown samples of the signature they were to imitate, and allowed to practice (generally 5-10 minutes) until they felt ready to produce the forgery samples. Each forger imitated the signature of one of the four subjects.

The nine measures described above were evaluated on each reference set, and the mean and standard deviation of each measure within each set were computed.

It should be noted that to make the parameter-

matching procedure automatic, a set of rules is needed for selecting the number $N_i$ and set $\{M_{ij}\}$ of measures to use in computing the error magnitude $E_i$ for subject i, and for establishing the proper threshold $C_i$ to obtain the desired low level of false rejections.

With reference to FIG. 2, an exemplary procedure was established as follows: For each subject, the nine measures were rank ordered (step 200 of the figure) according to the standard deviation of each measure (normalized to the corresponding mean) over that subject's reference set. The reference error was then repeatedly computed for each signature in the reference set, using successively larger subsets of the nine rank-ordered measures. It was observed that subsets of the best three measures would offer only slightly better discrimination between valid and forged signatures than would subsets of the best two measures. Subsets of four measures would offer substantially better discrimination. However, when more than four measures were considered, the variability over the reference set was observed to increase. Therefore, on the basis of the existing data, the four top-ranked measures were chosen (Step 210). The largest reference error was computed (Step 220), and the threshold value $C_i$ was arbitrarily set at a value 10% greater than that value (Step 230 of FIGS. 1 and 2). This value is readily adjusted in accordance with false rejection statistics in a given population.

The parameter-matching procedure was applied to the valid and forged signatures of subjects SG, FS, WN, and EP, using the four best measures for each in the computation of the entrant errors. The results, displayed in FIGS. 3 - 6, show the magnitude of error for the 10 valid signatures in the left group of bars and the forgeries in the right group of each plot. The dotted line is the value of $C_i$ for each subject. The four measures chosen for each subject are also listed in each plot.

It is apparent from the figures that the FS (FIG. 4) and SG (FIG. 3) forgeries could be readily discriminated from the valid signature reference set. The WN (FIG. 5) forgeries were detectable. However, the WN reference set displayed enough variability to suggest that the threshold should be set higher than the adopted 10% margin, in order to reduce false rejections. Such a change, however, would be liable to result in the acceptance, as valid, of forgeries only slightly better than those that were made. The EP (FIG. 6) forgeries were quite skillfully matched to the statistics of the measures used, and only 4 out of 10 were rejected. (It should be noted that a second-stage verification procedure involving more detailed *shape* analysis would be likely to succeed in rejecting such forgeries as survive the parameter-matching procedure.) Significantly, the second signature in the EP reference set had a substantially larger error than the other nine. If that signature were removed from the reference set, the threshold would be lowered to a level where only one of the forgeries would be accepted as valid.

## Claims

1. In a communications network, a method for controlling access to a system such that when an entrant signature is accepted, responsive means are activated, with the result that access to the system becomes available, the method comprising:

   A) in an initializing phase,

   a) receiving from input means, and digitally recording, a reference set which consists of a multiplicity of reference signatures; and

   b) calculating, for each of at least four predetermined spatial and/or dynamic signature properties, to be referred to as "measures", an average and a deviation of that measure over the reference set; and

   B) in a verification phase, at least a first verification stage comprising the steps of:

   c) receiving from input means, and digitally recording, at least one entrant signature;

   d) evaluating at least some of the measures on the entrant signature;

   e) calculating an entrant error associated with the entrant signature, the entrant error representing a mismatch between at least some of the measures as evaluated on the entrant signature and the same measures as averaged over the reference set; and

   f) comparing the entrant error to a threshold value such that the entrant signature is accepted if the entrant error is *less than*, or *less than or equal to*, the threshold value, CHARACTERIZED IN THAT

   C) the initializing phase further comprises the steps of:

   (g) after step (b), selecting the at least three measures having the smallest deviations over the reference set;

   h) calculating a reference error associated with each reference signature, each reference error representing a mismatch between the selected measures as evaluated on that reference signature and the same measures as averaged over the reference set; and

   i) determining the threshold value based

on the reference errors; and

D) the entrant error of step (e) is calculated with respect to the selected at least three measures.

2. The method of claim 1, wherein step (b) comprises calculating at least one measure selected from the group consisting of: the total signature length, the total signature duration, the rms speed, the rms centripetal acceleration, the rms tangential acceleration, the rms total acceleration, the rms jerk, the mean value of the horizontal speed, and the integral with respect to time of the magnitude of the centripetal acceleration.

3. The method of claim 1, wherein step (b) comprises calculating at least one measure which represents, or is derived from, a path-normal or path-tangential property of the reference signatures.

4. The method of claim 1, wherein the average of each measure over the reference set is the statistical mean of that measure over the reference set, and the deviation of each measure over the reference set is the standard deviation.

5. The method of claim 4, wherein:

a) the step of calculating entrant error comprises evaluating the expression

$$E_i = \left[ \sum_{j=1}^{N_i} ((M_{ij} - \mu_{ij}) / \sigma_{ij})^2 \right]^{1/2} ,$$

where $E_i$ denotes the i-th entrant error, $M_{ij}$ denotes the j-th one of the selected measures evaluated for the i-th entrant signature, $N_i$ denotes the total number of measures selected for the i-th entrant, $\mu_{ij}$ denotes the mean of the j-th measure over the i-th reference set, $\sigma_{ij}$ denotes the standard deviation of the j-th measure over the i-th reference set, and the summation is carried out over the selected measures; and

b) the step of calculating reference errors comprises treating each reference signature, in turn, like an entrant signature and calculating the corresponding entrant error.

6. The method of claim 5, wherein the step of determining the threshold value comprises identifying the largest reference error, and selecting a threshold value which is greater than or equal to the largest reference error.

7. The method of claim 1, wherein:

a) the initializing phase further comprises digitally storing, on a storage medium that is local with respect to at least one entrant, data which comprise: the identities of the selected measures, the averages and deviations of the selected measures over the reference set, and the threshold value; and

b) the first verification stage further comprises reading the locally stored data.

8. The method of claim 1, wherein step (b) comprises calculating averages and deviations of at least five measures, and step (g) comprises selecting exactly four measures.

9. In a communications network, an access-controlled system which includes responsive means that are activated when an entrant signature is accepted, with the result that access to the system is made available, the system further comprising:

a) means for receiving and digitally recording data which represent a reference set consisting of a multiplicity of reference signatures, and for subsequently receiving and digitally recording data which represent at least one entrant signature;

b) digital processing means for evaluating, on each of the reference signatures and the entrant signature, at least four predetermined spatial and/or dynamic properties, to be referred to as "measures";

c) digital processing means for calculating an average and a deviation of each measure over the reference set;

d) digital processing means for calculating an entrant error associated with the entrant signature, the entrant error representing a mismatch between at least some of the measures as evaluated on the entrant signature and the same measures as averaged over the reference set; and

e) digital processing means for comparing the entrant error to a threshold value such that the entrant signature is accepted if the entrant error is *less than, or less than or equal to*, the threshold value, CHARACTERIZED IN THAT

f) the system further comprises digital processing means for selecting the at least three measures having the smallest deviations over the reference set;

g) the entrant-error calculating means are adapted to calculate the entrant error with respect to the selected at least three mea-

sures;

h) the system further comprises digital processing means for calculating a reference error associated with each reference signature, each reference error representing a mismatch between the selected measures as evaluated on that reference signature and the same measures as averaged over the reference set; and

i) the system further comprises digital processing means for determining the threshold value based on the reference errors.

10. The system of claim 9, wherein for the i-th entrant and the j-th measure, the average measure is the statistical mean, denoted $\mu_{ij}$, of that measure over the reference set; the deviation is the standard deviation, denoted $\sigma_{ij}$, of that measure over the reference set; and the means for calculating entrant error and reference error comprise means for evaluating the expression

$$E_i = \left[ \sum_{j=1}^{N_i} ((M_{ij} - \mu_{ij}) / \sigma_{ij})^2 \right]^{1/2} ,$$

where $N_i$ denotes the total number of measures selected for the i-th entrant; the summation is carried out over the selected measures; if entrant error is being calculated, $E_i$ denotes the entrant error and $M_{ij}$ denotes the j-th one of the selected measures evaluated over an entrant signature of the i-th entrant; and if reference error is being calculated, $E_i$ denotes the reference error and is calculated for each reference signature as if that signature were an entrant signature.

11. The system of claim 10, wherein the threshold-determining means comprise means for identifying the largest reference error and for selecting a threshold value which is greater than or equal to the largest reference error.

12. The system of claim 9, further comprising:

a) means for digitally storing, on a storage medium that is local with respect to at least one entrant, data which comprise: the identities of the selected measures, the averages and deviations of the selected measures over the reference set, and the threshold value; and

b) means for reading the locally stored data.

13. In a communications network, a method for controlling access to a system such that when an entrant signature is accepted, responsive means are activated, with the result that access to the system becomes available, the method comprising:

a) receiving from input means, and digitally recording, at least one entrant signature;

b) evaluating, on the entrant signature, at least three spatial and/or dynamic properties, to be referred to as "measures", the at least three measures constituting a measure set;

c) reading reference data from a digital storage medium that is local with respect to at least one entrant, the reference data including the mean and deviation of each measure as evaluated over a reference set which comprises a multiplicity of reference signatures;

d) comparing the entrant signature to the reference data by a process that comprises calculating at least one entrant error, the entrant error representing a mismatch between the measures as evaluated on the entrant signature and the same measures as averaged over the reference set; and

e) comparing the entrant error to a threshold value such that the entrant signature is accepted if the entrant error is *less than*, or *less than or equal to*, the threshold value, CHARACTERIZED IN THAT

f) the threshold value is based on at least one reference error, each reference error being defined as a mismatch between the measures, as evaluated on one of the reference signatures, and the same measures as averaged over the reference set;

g) the measure set is a proper subset of a measure superset which contains at least four measures, the measure set consisting of the at least three measures, selected from the superset, which have the smallest deviations over the set of reference signatures; and

h) the reference data further include the threshold value, and further include information which identifies the selected at least three measures.

14. In a communications network, an access-controlled system which includes responsive means that are activated when an entrant signature is accepted, with the result that access to the system is made available, the system further comprising:

a) means for receiving from input means, and digitally recording, at least one entrant signature;

b) digital processing means for evaluating, on the entrant signature, at least three spatial and/or dynamic properties, to be referred to as "measures", the at least three measures constituting a measure set;

c) means for reading reference data from a digital storage medium that is local with respect to at least one entrant, the reference data including the mean and deviation of each measure as evaluated over a reference set which comprises a multiplicity of reference signatures;

d) digital processing means for comparing the entrant signature to the reference data by a process that comprises calculating at least one entrant error, the entrant error representing a mismatch between the measures as evaluated on the entrant signature and the same measures as evaluated over the reference set; and

e) digital processing means for comparing the entrant error to a threshold value such that the entrant signature is accepted if the entrant error is *less than, or less than or equal to*, the threshold value, and for activating the responsive means if the entrant signature is accepted, CHARACTERIZED IN THAT

f) the threshold value is based on at least one reference error, each reference error being defined as a mismatch between the measures, as calculated on one of the reference signatures, and the same measures as averaged over the reference set;

g) the measure set is a proper subset of a measure superset which contains at least four measures, the measure set consisting of the at least three measures, selected from the superset, which have the smallest deviations over the set of reference signatures; and

h) the reference data further include the threshold value, and still further include information which identifies the selected at least three measures.

FIG. 1

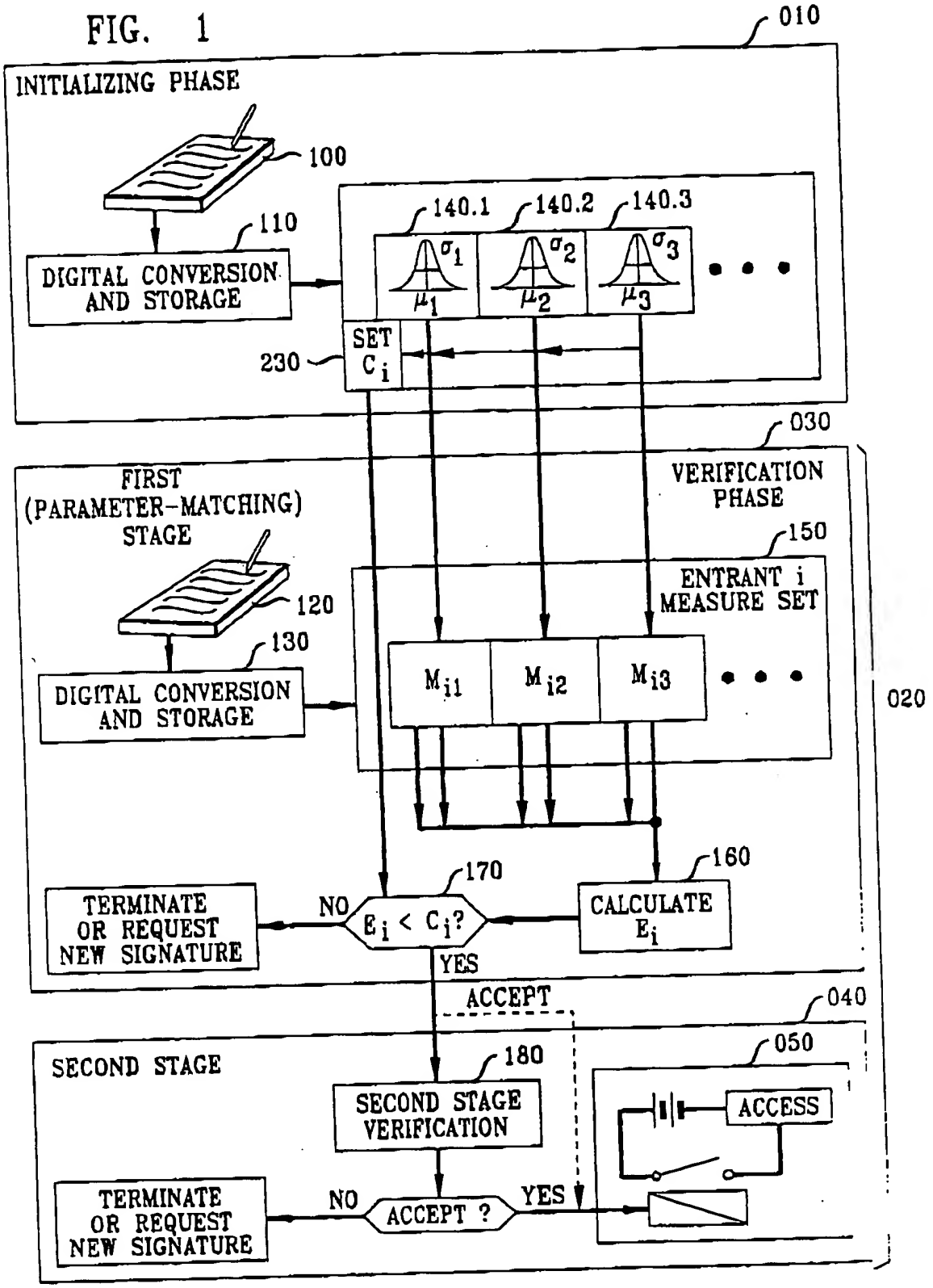

010
INITIALIZING PHASE
100
110
DIGITAL CONVERSION AND STORAGE
140.1
140.2
140.3
$\sigma_1$
$\sigma_2$
$\sigma_3$
$\mu_1$
$\mu_2$
$\mu_3$
230
SET $C_i$
030
VERIFICATION PHASE
FIRST (PARAMETER-MATCHING) STAGE
120
130
DIGITAL CONVERSION AND STORAGE
150
ENTRANT i MEASURE SET
$M_{i1}$
$M_{i2}$
$M_{i3}$
020
160
CALCULATE $E_i$
170
$E_i < C_i$?
NO
TERMINATE OR REQUEST NEW SIGNATURE
YES
ACCEPT
040
SECOND STAGE
180
SECOND STAGE VERIFICATION
050
ACCESS
TERMINATE OR REQUEST NEW SIGNATURE
NO
ACCEPT ?
YES

FIG. 2

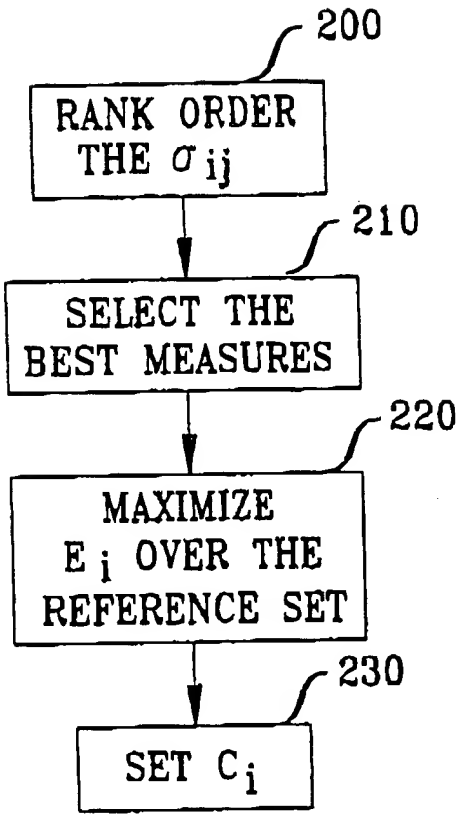

200
RANK ORDER THE $\sigma_{ij}$
210
SELECT THE BEST MEASURES
220
MAXIMIZE $E_i$ OVER THE REFERENCE SET
230
SET $C_i$

FIG. 3

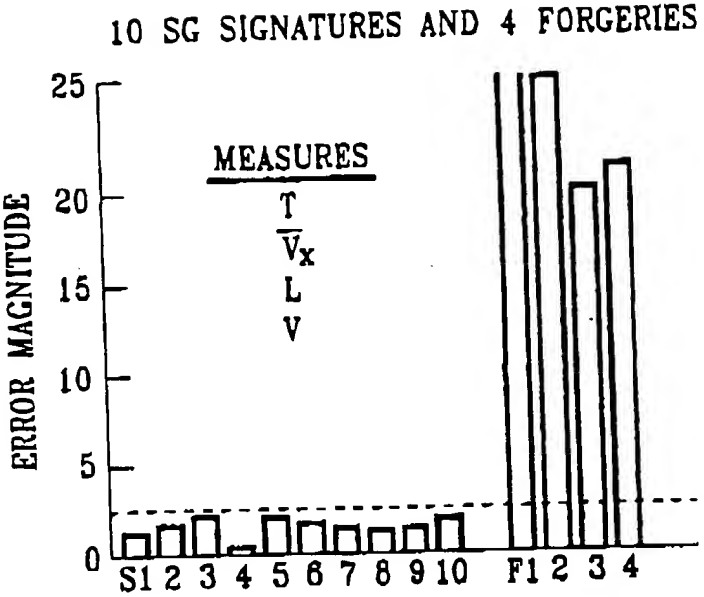

10 SG SIGNATURES AND 4 FORGERIES
ERROR MAGNITUDE
25
20
15
10
5
0
MEASURES
T
$\overline{V}_X$
L
V
S1 2 3 4 5 6 7 8 9 10 F1 2 3 4

FIG. 4

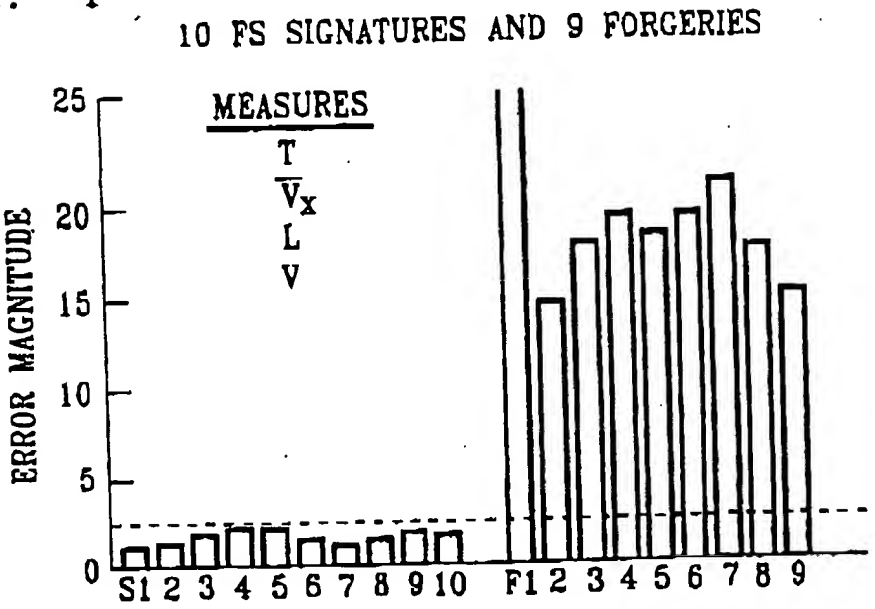

10 FS SIGNATURES AND 9 FORGERIES
ERROR MAGNITUDE
25
20
15
10
5
0
MEASURES
T
$\overline{V}_X$
L
V
S1 2 3 4 5 6 7 8 9 10 F1 2 3 4 5 6 7 8 9

FIG. 5

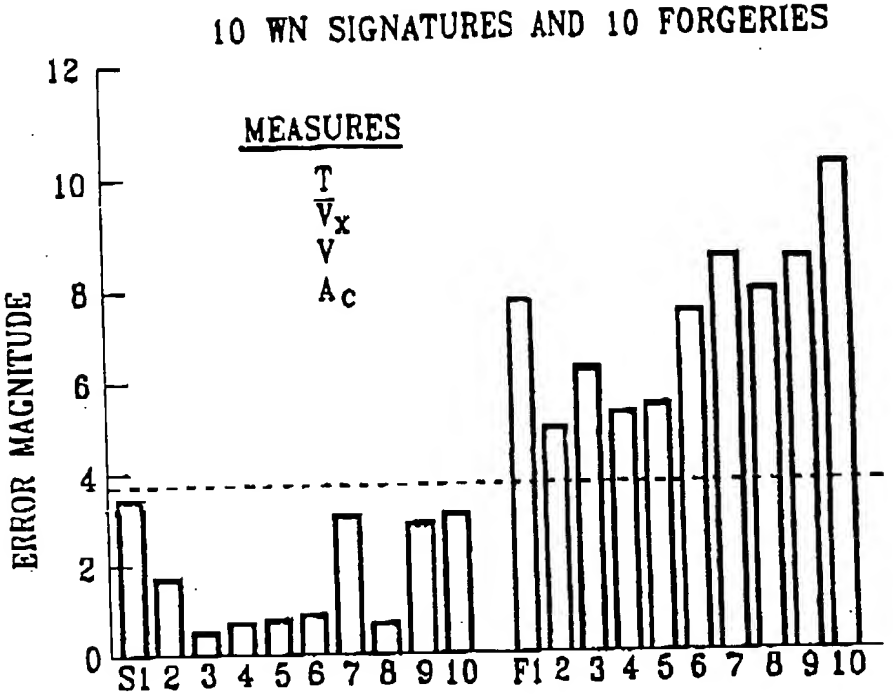
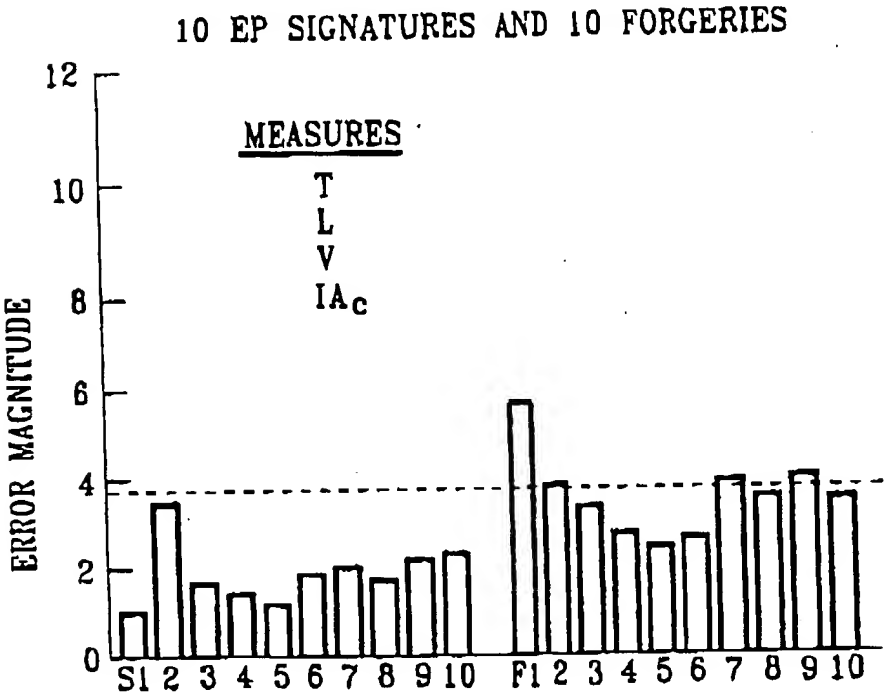

10 WN SIGNATURES AND 10 FORGERIES
MEASURES
T
$\overline{V}_X$
V
$A_C$
ERROR MAGNITUDE
0
2
4
6
8
10
12
S1 2 3 4 5 6 7 8 9 10 F1 2 3 4 5 6 7 8 9 10

FIG. 6


10 EP SIGNATURES AND 10 FORGERIES
MEASURES
T
L
V
$IA_C$
ERROR MAGNITUDE
0
2
4
6
8
10
12
S1 2 3 4 5 6 7 8 9 10 F1 2 3 4 5 6 7 8 9 10

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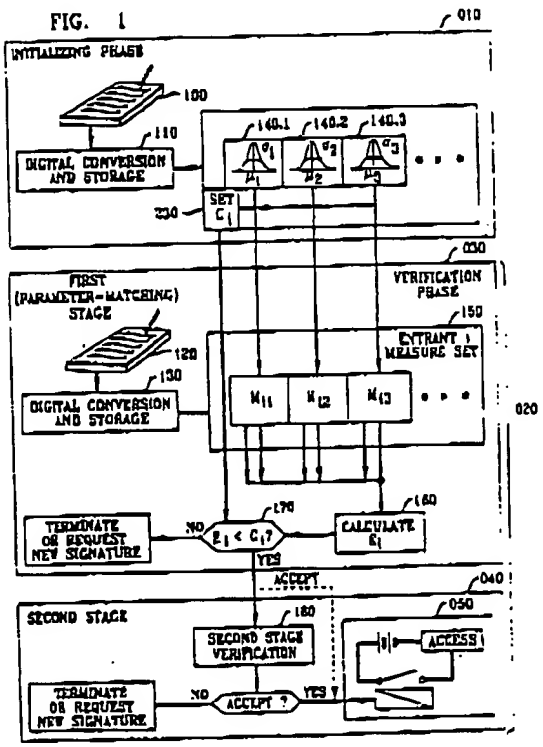
## (54) Method and apparatus for controlling a system, using signature verification.

(57) Forged signatures are discriminated from authentic signatures in a verification process which relies on dynamic signature properties. In an initialization phase (010) a reference set of authentic signatures is obtained. A set of dynamical properties (140.1, 140.2, 140.3) of the reference signatures is computed numerically. The most characteristic subset of such properties is selected and statistically analyzed to obtain a set of parameters for signature verification. An entrant signature is subsequently accepted or rejected (160, 170) based on its conformity to the parameters. An accepted signature is optionally passed along to a higher-level verification process. When a signature is accepted by the highest-level verification process, responsive means (050) are activated, resulting in the entrant's access to a system.

FIG. 1

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# EUROPEAN SEARCH REPORT

Application Number
EP 92 30 6284

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.5) |
|---|---|---|---|
| X | GB-A-2 104 698 (QUEST AUTOMATION LTD.)<br>* page 1, line 50 - line 63; table 1 *<br>* page 8, line 30 - line 34 *<br>* page 7, line 10 - line 17 *<br>* abstract * | 1-14 | G06K9/62<br>G07C9/00 |
| X | FR-A-2 649 509 (M. ACHEMLAL ET AL.)<br>* abstract *<br>* page 11, line 20 - page 12, line 24 * | 1-14 | |
| | | | TECHNICAL FIELDS SEARCHED (Int.Cl.5)<br>G06K |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 15 March 1994 | Sonius, M |

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